University of BRISTOL

System Level Evaluation of UL and DL Interference in OFDMA Mobile Broadband Networks

WCNC 2011

ccr centre for communications *research*

David Halls

29th March 2011

MOTOROLA

Outline

- Mobile Broadband Wireless Networks
- Motivation
- Link-level simulator
- Link-level abstraction
- System-level simulator
- Interference characterization results
- Summary

University of BRISTOL
Department of Electrical & Electronic Engineering

Mobile Broadband Wireless Networks

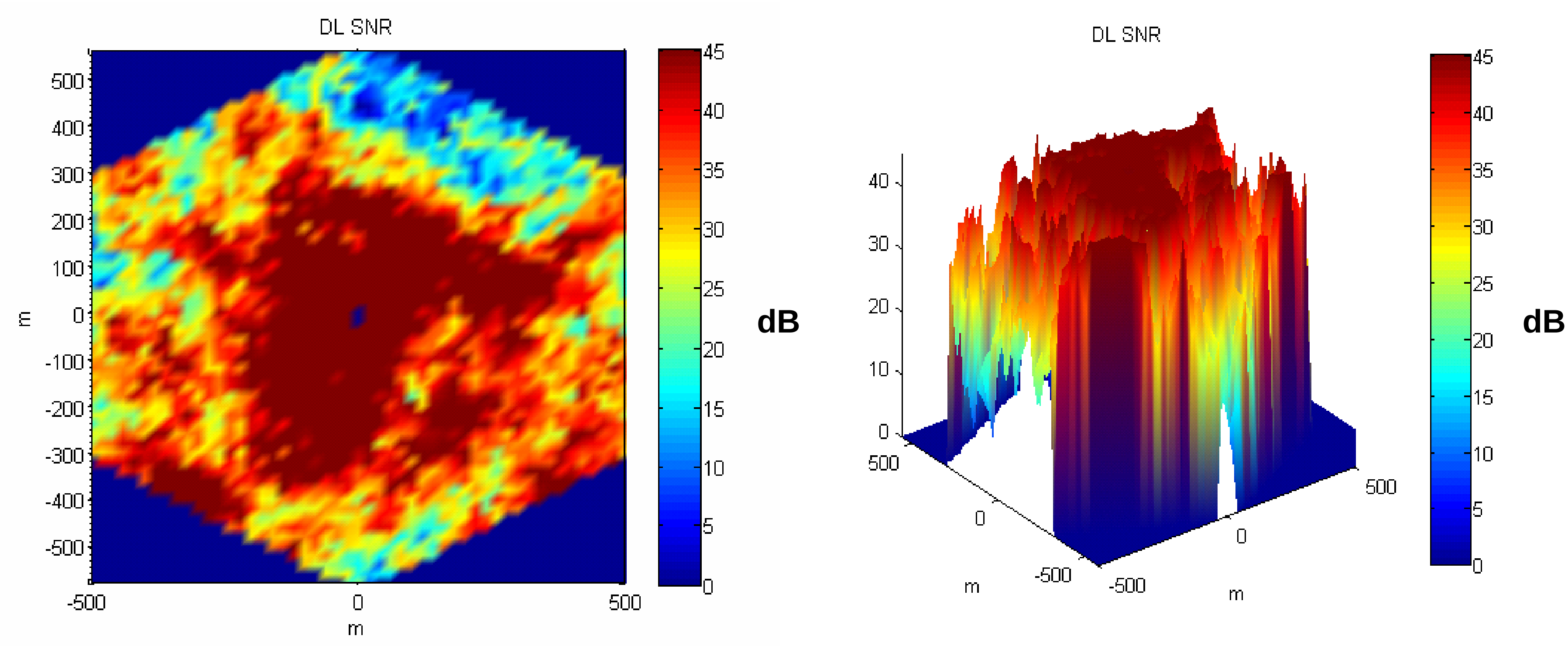
- Mobile Broadband Wireless Networks aim to bring the triple play of voice, data and media to a variety of handsets.
- The key attributes are:
  - High capacity (1Mbps+ user throughput),
  - Reliable Quality of Service (QoS),
  - Robust connection (even with high mobility),
  - Minimal power consumption.

University of BRISTOL
Department of Electrical & Electronic Engineering

Motivation

- Unless deployed correctly, Mobile Broadband Networks will collapse due to inter-cell interference.
- Inter-cell interference is <u>particularly acute at cell boundaries</u> and results in reduced throughput.
- Critical, pre-deployment, to accurately **a) characterize** and **b) manage** interference.
- Interference fluctuation from frame-to-frame is unpredictable <u>particularly on the UL</u>, as we do not know which user is transmitting at any one time, and if not combated this will reduce system capacity.

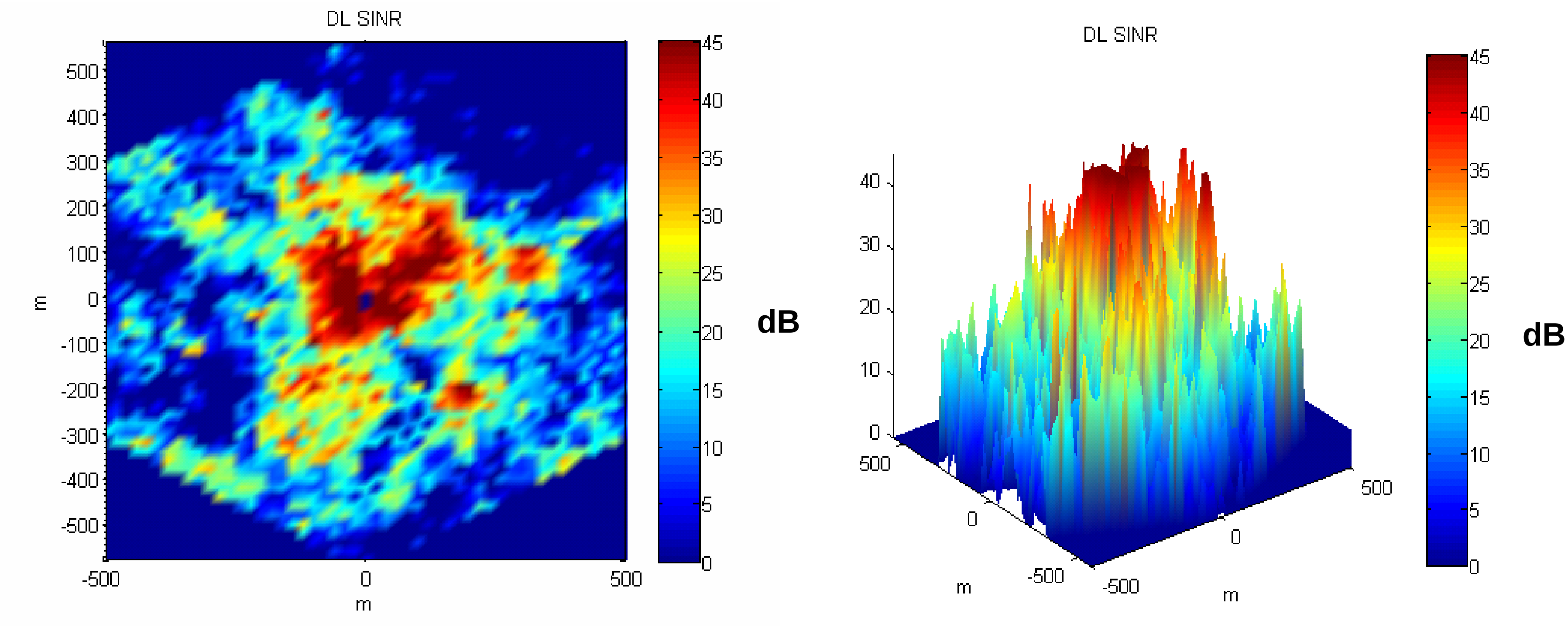
Motivation – What's The Problem?



2D and 3D surface plots of DL SNR.

University of BRISTOL
Department of Electrical & Electronic Engineering

Motivation – What's The Problem?



2D and 3D surface plots of DL SINR.

University of BRISTOL
Department of Electrical & Electronic Engineering

Why Not Characterize with Drive Testing?

- Drive testing has been used for validation and is important but only limited data can be logged.
- It is impossible to fully load and test a real-world network with multiple users, with different devices, applications and QoS requirements etc.
- We need to be able to test in a repeatable and controlled manner and collect comprehensive data for a multi-cell, multi-user environment.
- As a result we need a combination of real-world data AND rigorous simulation. Due to the sheer complexity of such simulation these issues are not well addressed in the literature.
- Drive-testing produces reams and reams of data, accurate simulation allows us to ‘drill-down’ into these results and provide a unique insight into real-world performance issues.

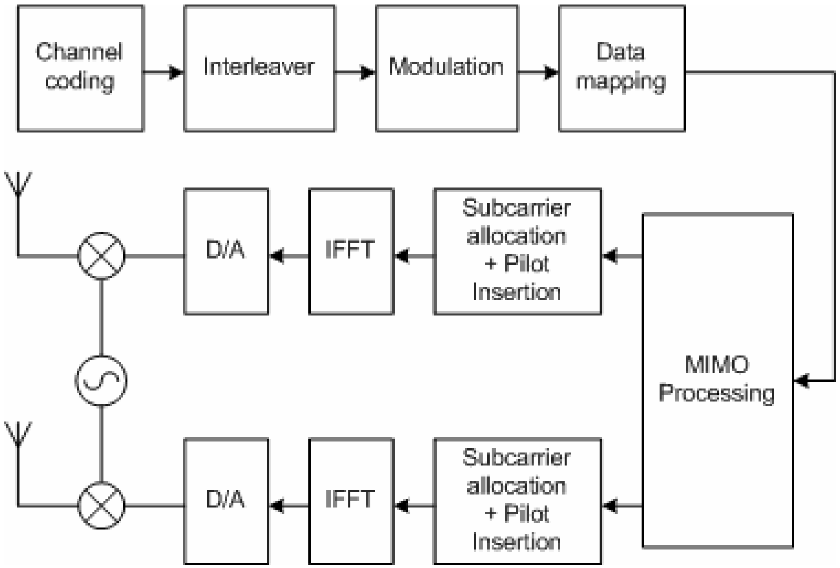
University of BRISTOL
Department of Electrical & Electronic Engineering

Solution – System-level Simulation

- Our system level simulator is based on WiMAX .16m but easily extensible to LTE, it enables a virtual deployment of a broadband network with standards compliant functionality, offers:
  - Extremely accurate modelling of MIMO MBWN under interference.
  - Implements temporal and spatial models for all users and <u>all</u> inter-cell interferers as well as realistic mobility with time evolution and correlated shadowing.
  - Models standards compliant PHY <u>and</u> MAC, not achieved by other simulators, with full DL <u>and</u> UL frame and AMC/AMS.
  - Precisely models a channel dependent scheduler (Motorola's WiMAX Proportional Fair scheduler with enhancements).
  - Models interference randomization through PUSC, interference coordination through FFR; and capacity improving and interference reduction techniques through MIMO and beamforming (up to 8x2).
  - Models 1 tier of interfering BS with dynamic loading and scheduling of interferers all with bit-level accuracy.

University of BRISTOL
Department of Electrical & Electronic Engineering

Link-level Simulator



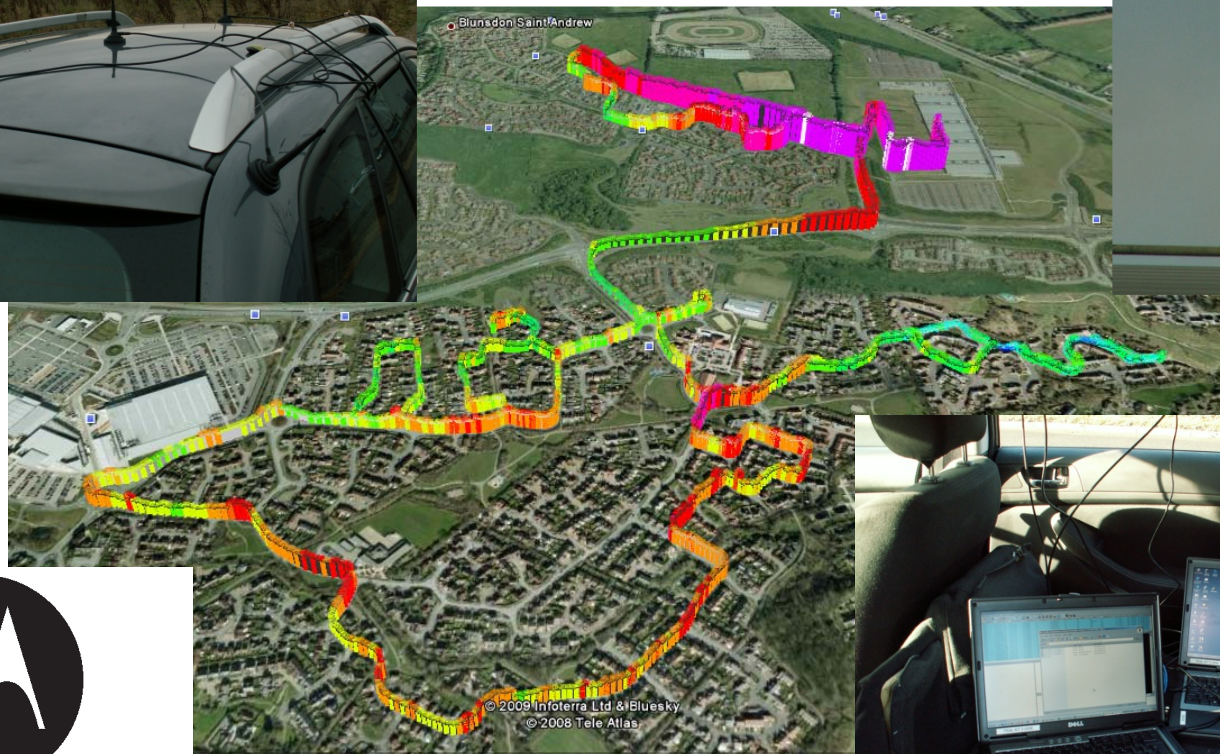
Mobile WiMAX functional stages.

Parameter		Value
EIRP (dBm)		46.5
Centre Frequency (MHz)		3525
Channel bandwidth (MHz)		5
UL/DL Ratio		3:1
Sampling frequency F_s (MHz)		5.6
Sampling period $1/F_s$ (µs)		0.18
Subcarrier frequency spacing $\Delta f = F_S / N_{FFT}$ (kHz)		10.94
Useful symbol period $T_b = 1/\Delta f$ (μs)		91.4
Guard Time $T_g = T_b / 8$ (μs)		11.4
OFDMA symbol duration $T_s = T_b + T_g$ (μs)		102.9
	DL PUSC	**UL PUSC**
Number of used subcarriers (N_{used})	421	409
Number of pilot subcarriers	60	136
Number of data subcarriers	360	272
Number of data subcarriers/subchannel	24	16
Number of subchannels	15	17
Number of users (N_{users})	3	3
Number of subchannels/user	5	4

Simulation Parameters.

[1] M. Tran, D. Halls, A. Nix, A. Doufexi, and M. Beach, "Mobile WiMAX: MIMO Performance Analysis from a Quality of Service (QoS) Viewpoint," *IEEE WCNC,* pp. 1-6, April 2009.

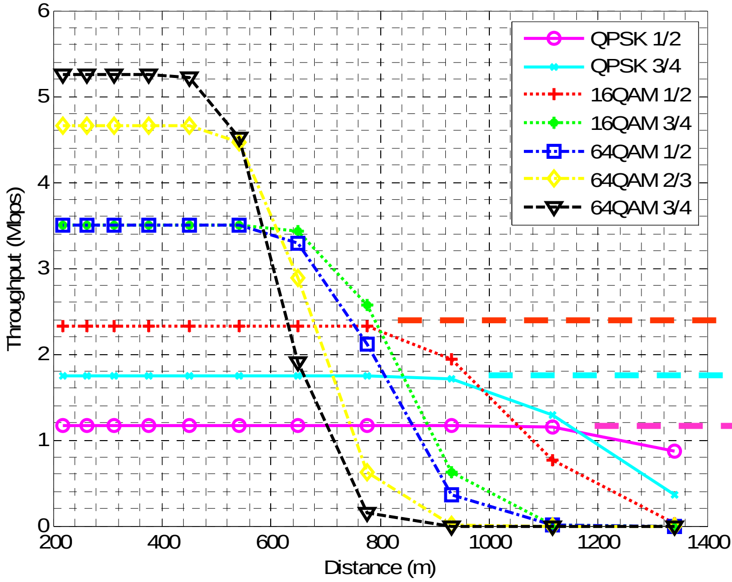
Link-level Validation – Motorola, Swindon



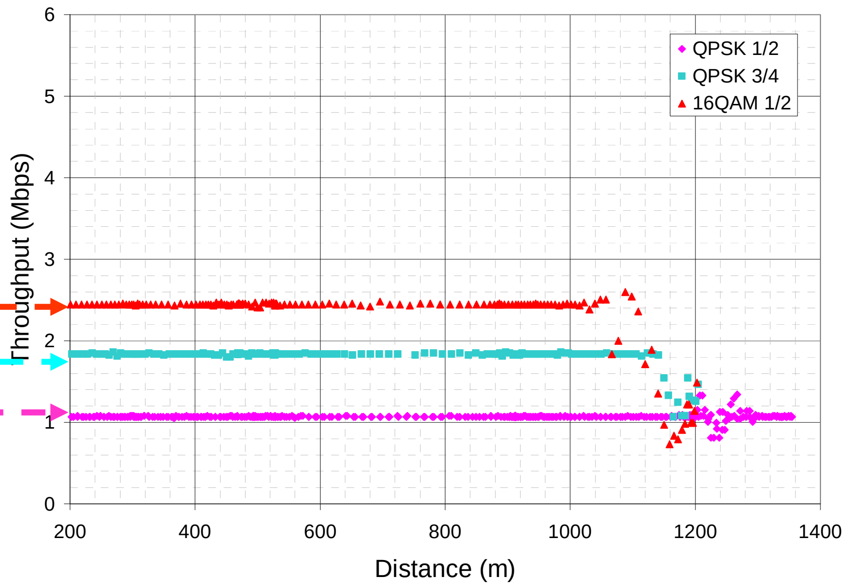
MOTOROLA

Link-level Validation

- All simulated Physical Layer (PHY) throughputs were within 5% of those measured.
- Measured and simulated distances also show close correlation.



Simulated tput vs. distance (2x2 STBC).



Measured tput vs. distance (2x2 STBC).

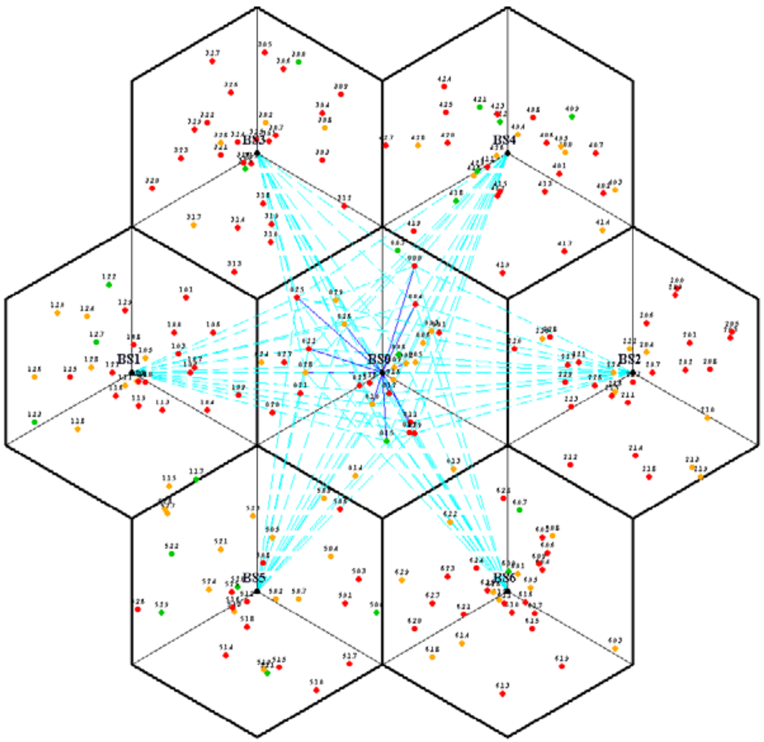
University of BRISTOL
Department of Electrical & Electronic Engineering

Link-level Complexity - Downlink

- For DL ‘slot’ we calculate the link quality between all 30 users in the central cell and each of the 7 BSs, over all 512 subcarriers.

Wanted signal

Interfering signal



- Vehicular
- Pedestrian
- Indoor pedestrian

Link calculations per slot, DL scenario.

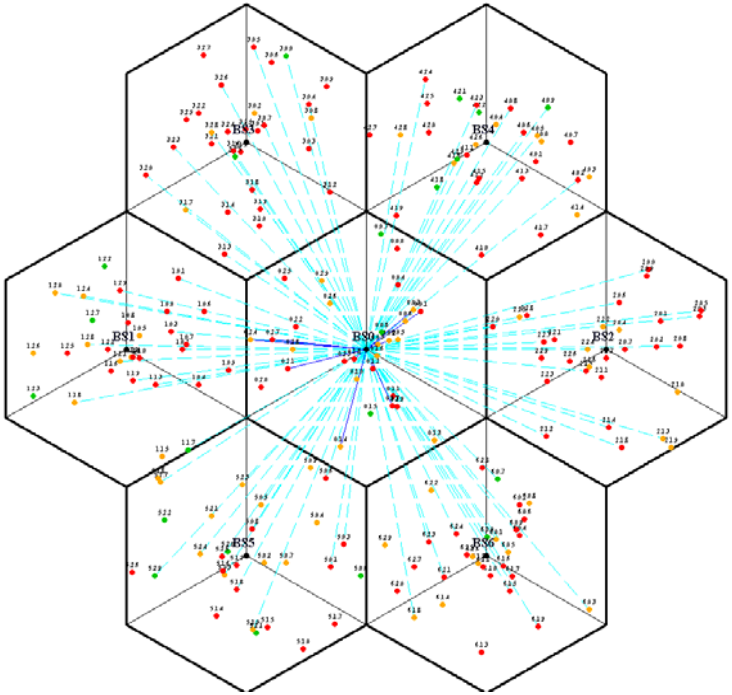
University of BRISTOL
Department of Electrical & Electronic Engineering

Link-level Complexity - Uplink

- For the UL 'slot', we need to calculate the link quality between all of the 180 MSs in the surrounding cells and the central BS for all 512 subcarriers.

Wanted signal

Interfering signal



- Vehicular
- Pedestrian
- Indoor pedestrian

Link calculations per slot, UL scenario.

University of BRISTOL

Department of Electrical & Electronic Engineering

Link-level Complexity

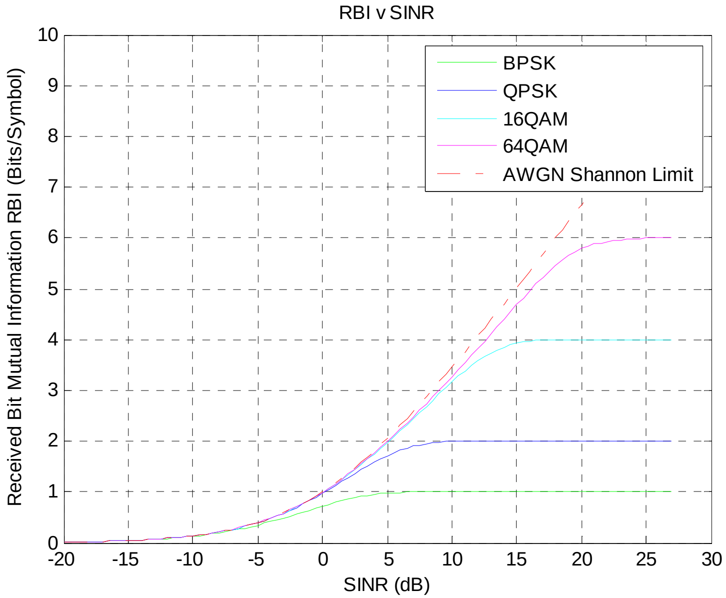
- This amounts to 107,520 links per 100μs time slot – more than 1 billion links per second!!
- This is in addition to creating the channel and performing the permutation, AMS/AMC, scheduling, HARQ, power controlling, mobility etc etc.
- With **bit-level** simulation we must average over a large number of channel instances. Each link performance curve takes 10 hours to produce, system results would take weeks!
- We use an instantaneous PHY abstraction model to reduce the complexity to a manageable level, now each 5ms frame takes ~10secs.
- The simulator uses an efficient combination of C++ and Matlab and can be run on a Condor cluster giving close to real time performance.

Link-level Abstraction – RBIR MIESM

- This efficiently models dynamic behaviour and provides an **instantaneous** look-up based on the current channel conditions.
- It compresses the vector of received SINRs over a coded block into a single Effective SINR which is then mapped to BLER by AWGN look-up.
- Can also predict BLER including MIMO and H-ARQ performance and it was validated against our link-level simulator for all MCS/MIMO modes.

$$RBI(\gamma, m) = E_{XY}\left\{\log_2 \frac{P(Y \mid X, \gamma)}{\sum_X P(X)P(Y \mid X, \gamma)}\right\}$$

$$RBIR = \frac{\sum_{n=1}^{N} RBI(\gamma_n)}{N}$$



University of BRISTOL
Department of Electrical & Electronic Engineering

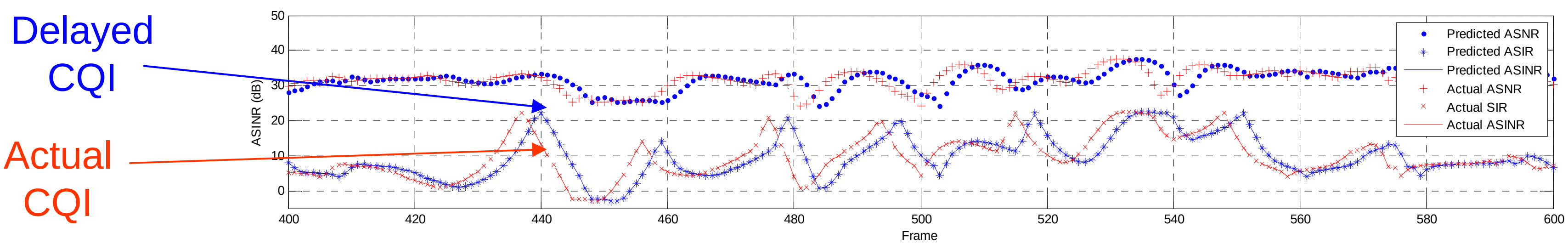
Simulator Functionality

- Models a tri-sector, multi-cell environment with micro and macro scenarios,
- Exhaustively models all interferers,
- Models full size TDD frame structure for UL/DL with subcarrier randomisation (PUSC),
- Implements AMC/AMS with all MCS modes and up to 8x2 MIMO (STBC, SM open- and closed-loop with codebooks, MRT, MRC),
- Implements hard FFR, HARQ, Power Control and hard handover,
- Implements a PF scheduler with service prioritization and multiple flows per user,
- Uses a sophisticated correlated shadowing model and correlated (MIMO) fast fading with realistic MS mobility and traffic mixes,
- Obtains complexity reduction using an accurate and validated PHY abstraction model.

University of BRISTOL
Department of Electrical & Electronic Engineering

Interference Characterisation

- Channel Quality Information (CQI) e.g. average (A)SINR, is used by AMC algorithms to select the best MCS mode for each user on a frame-by-frame basis.
- CQI information available to the AMC algorithm is delayed thus causing inaccuracies in mode selection.

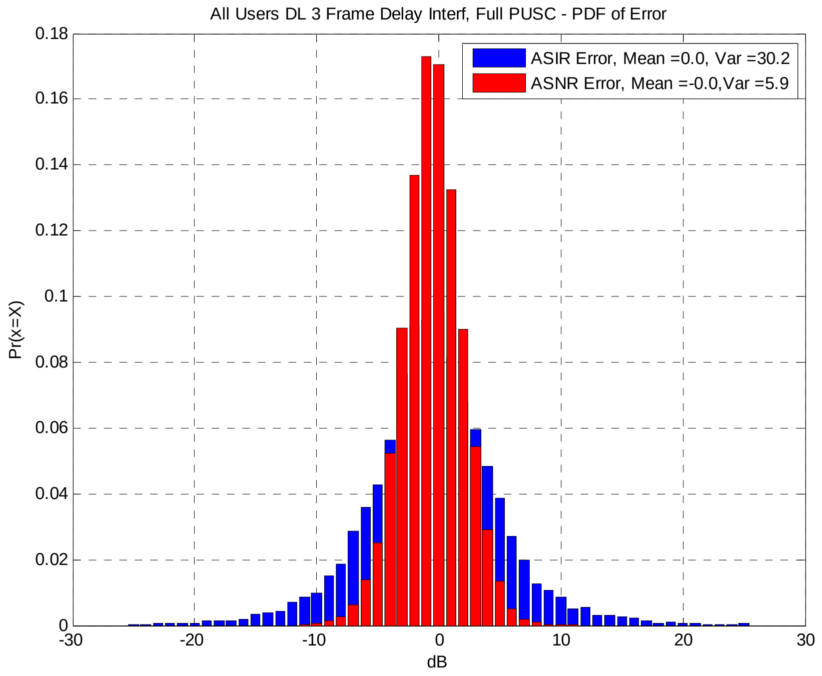


- In this study we looked at the effect of a 1-frame and 3-frame CQI delay, on mode selection and throughput, compared with perfect CQI knowledge (i.e. ideal AMC).
- *Assume SISO, UL and DL, 5MHz profile, 10 users per sector, 3km/hr, macro, single BE conn/user, fully loaded, full buffer.*

University of BRISTOL
Department of Electrical & Electronic Engineering

Signal and Interference Variability

- Over 1000 frames, for all users, we calculated the error between the delayed frame ASNR/ASIR used by the AMC algorithm and the current frame ASNR/ASIR.



PDF of ASNR and ASIR error for all DL users, 3-frame delay

- In the 3-frame delay case, for frame *k*:

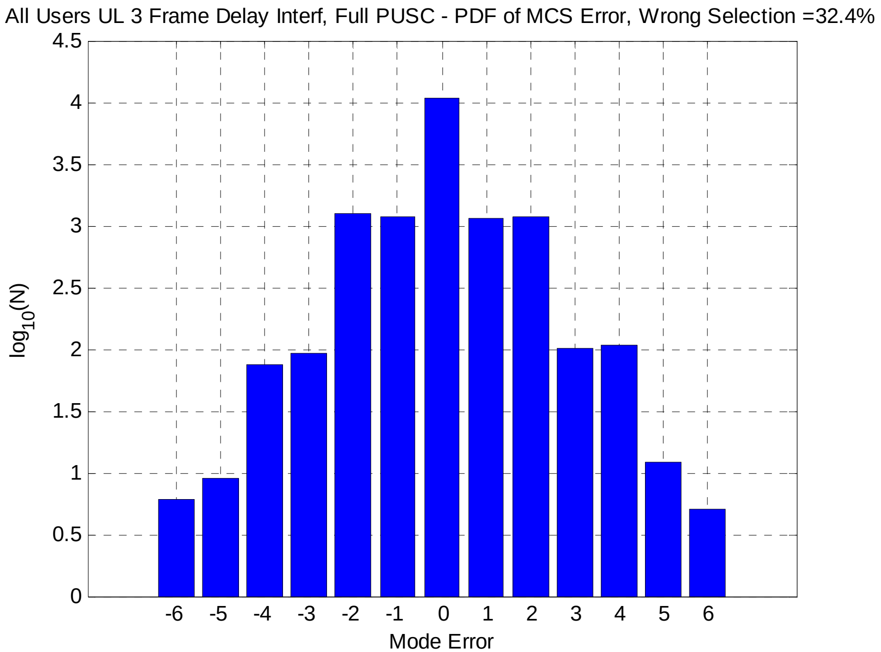
$$ASIR\_Err_k = ASIR_k - ASIR_{k-3}$$
$$ASNR\_Err_k = ASNR_k - ASNR_{k-3}$$

- We can see from the PDF that ASIR error variance is much higher than ASNR error variance.

University of BRISTOL
Department of Electrical & Electronic Engineering

Mode Choice Error

- As mode selection is based on the CQI from the delayed frame, ASINR errors translate to MCS errors.
- As the ASIR error dominates the ASNR, it is the variation in interference that dominates AMC performance.

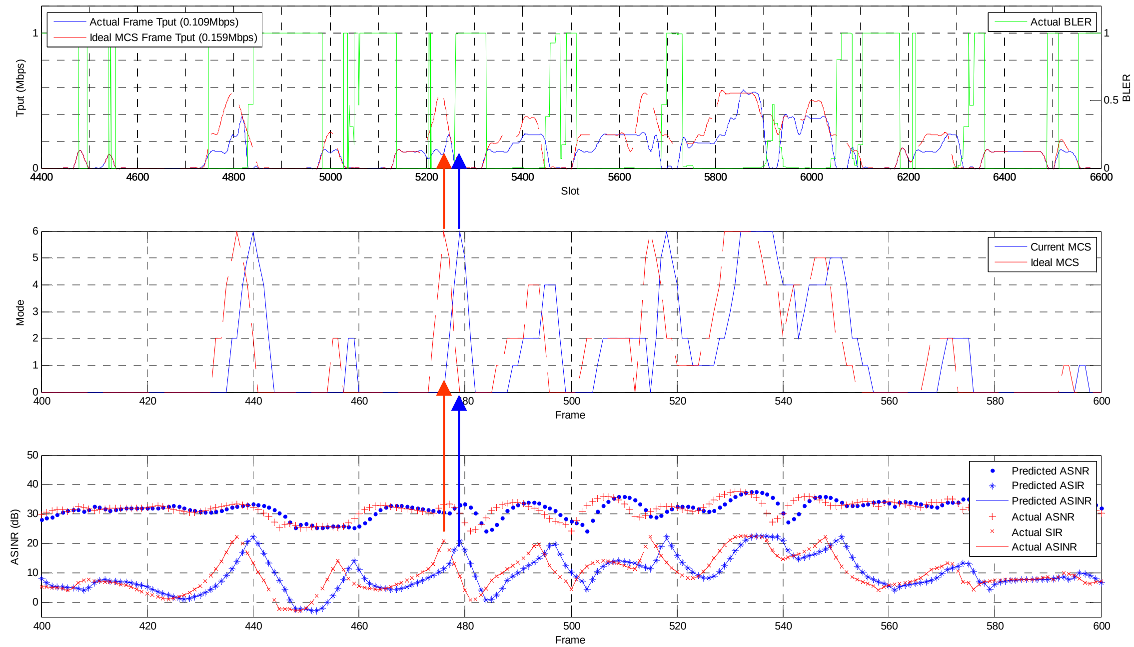


UL MCS selection error, 3-frame delay

University of BRISTOL
Department of Electrical & Electronic Engineering

Impact on Throughput

- AMC errors lead to capacity reduction, a 29% reduction due to 3-frame delayed CQI is seen below.
- Current schedulers are strongly affected by interference and are unable to cope with this frame-to-frame variation.



MS 2.0 DL performance, frames 400-600

University of BRISTOL
Department of Electrical & Electronic Engineering

Mode Choice Error and Capacity Reduction

- As mode selection is based on the CQI from the delayed frame ASINR errors translate to MCS errors.
- If too high a mode is used, errors will occur and capacity is lost. If too low a mode is chosen capacity is wasted.
- As the ASIR error dominates the ASNR, it is the variation in interference that dominates AMC performance.
- On the DL, incorrect mode usage fell 22.7% to 9.1% when interference was orthoganalised.
- Using 3-frame delay rather than ideal MCS knowledge reduced the user throughput by up to:
  - 48% on the downlink,
  - 22% on the uplink.
- Schedulers are strongly affected by interference and are unable to cope with the frame-to-frame variation.

Summary

- Without suitable interference characterization and management, multi-billion dollar networks will collapse under full load.
- System-level simulation is required, and is highly complex. Complexity reduction techniques such as PHY abstraction are necessary to generate the results shown.
- It is the frame-to-frame fluctuations in interference, and not the received signal-level that dominate CQI inaccuracies.
- Imperfect CQI lead to AMC errors and this reduces user throughput by up to 50%.
- Schedulers are strongly affected by interference and are unable to cope with the frame-to-frame variation.

University of BRISTOL
Department of Electrical & Electronic Engineering

Future Work

- Improve the performance of mobile broadband networks by reducing the impact of interference:
  1. Interference randomization (e.g. subcarrier permutation),
  2. Interference cancellation, (e.g. beamforming),
  3. Interference coordination, (e.g. cluster controlling).
- Combine the simulator with accurate 3D polarmetric field patterns and 3D urban ray tracing to further enhance simulation accuracy.
- Adapting simulator to model LTE, and new deployment scenarios including heterogeneous networks.
- Apply the simulators capabilities in the field of green BS,
- Study the performance of higher layer performance such as video streaming.
- Continue to compare simulation with drive-test results to provide validation and insight into real-world issues.

University of BRISTOL

Any Questions?

david.halls.03@bris.ac.uk

[2] D. Halls, A. Nix and M. Beach, “System Level Evaluation of UL and DL Interference in OFDMA Mobile Broadband Networks," *IEEE WCNC 2011*

[3] D. Halls, A. Nix and M. Beach, “System Level Evaluation of Interference in Vehicular Mobile Broadband Networks," *IEEE VTC Spring 2011*